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Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE CALIFORNIA

FURTHER INVESTIGATIONS

OF

STORM-TIME SUB ELF EMISSIONS

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SUMMARY

This report is concerned with the following properties of certain types of sub ELF emissions ($\Delta f = 0.2$-5 cps) observed during magnetic storms:

1. The aural characteristics of the emissions obtained from time-compressed magnetic tape.
2. The frequency-time (f-t) characteristics of the emissions as displayed on sonagrams.
3. The degree of simultaniety of emissions observed simultaneously at widely separated locations (the four Lockheed Pacific Ocean Stations).
4. The relationships between the occurrence times of the emissions and the following quantities
   a. Magnetic Kp index
   b. Local time of day
   c. Local sunset

Perhaps the most interesting result of the investigation is the observation that storm-time sub ELF emissions seem to excite natural resonances in the exosphere. This effect is explained in terms of an existing theoretical model.

Also of interest is the observation that the signals are most frequently observed near 800 PM local time. The occurrence time seems to indicate that the signal source is asymmetric with respect to the sun-earth line.

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ILLUSTRATIONS

I. INTRODUCTION

The purpose of the present project was to investigate in detail the characteristics of a particular type of sub ELF emission observed during magnetic storms. On an amplitude-time (waveform) display the emission is generally less regular than Pc 1 oscillations (pearls, hm emissions) but more regular than Pi 1 events (noise bursts). Hence the signals might be placed in an intermediate Pc 1 - Pi 1 category. On a frequency-time (f-t) display the emission is characterized by an irregularly spaced rapidly rising frequency fine structure (see fig. 1). When the signal is monitored aurally from time compressed magnetic tape (speed-up factor about 1600), it is characterized by a sound resembling bubbles being blown under water. We refer to these signals informally as "gurglers". Results of preliminary observations of these emissions have been presented elsewhere (Tepley et al., 1963; Tepley and Amundsen, 1964a), and the properties of gurglers and other types of sub ELF emissions were compared. The present investigation was primarily concerned with the determination of the degree of simultaniety of occurrence of gurglers at the four Lockheed Pacific Ocean stations (Palo Alto, Kauai, Canton Island, and Tongatapu). It was found that the emissions are usually localized to a single station. Occasionally the emissions are observed simultaneously at two stations. The event of 10 Feb. 1963 shown elsewhere (Tepley et al., 1963; Tepley and Amundsen, 1964a) is the only case observed so far of simultaneous occurrence at 3 stations of a clearly defined gurgler. Our inability to find other simultaneous occurrences of the signals at the four Pacific Ocean stations was a rather surprising result since the 10 Feb. 1963 event was found with little difficulty at an early date.

In the course of the investigation, we also considered the properties of other types of storm-time sub ELF emissions which were also characterized aurally by rather bubbly sounds but which exhibited a less clearly defined f-t fine structure. Perhaps the most interesting result of the investigation is the observation that both gurglers and apparently related storm-time emissions seem to excite natural resonances in the exosphere in the approximate frequency range 0.1-1 cps. The observation of these apparent resonance bands was first reported elsewhere (Tepley et al., 1964). The properties of the bands have been interpreted in terms of an existing model (Tepley and Amundsen, 1964b).

Another interesting result is the observation that the above emissions are observed most frequently near 800 PM local time. It appears that this effect is not influenced in any simple way by the time of local sunset and therefore is probably not related to ionospheric attenuation of downcoming hydromagnetic waves. Hence the occurrence time of the emissions is probably directly related to the behavior of the signal source which must be asymmetric with respect to the sun-earth line.

II. CLASSIFICATION OF SIGNALS

In general it seems that transitions between any two categories of micropulsations are continuous. Hence, classification of micropulsations into distinct categories is not rigorously possible and all attempts at classification run into difficulties associated with the observation of intermediate categories. An example of this type of difficulty arose in the present investigation. Specifically the f-t characteristics of the fine structured storm-time sub ELF emission shown in the sonagram of fig. 1 differ greatly in appearance from other types of sub ELF emissions; hence the signal seems to merit being placed in a separate category. Also the bubbling sound produced by the signal on aurally monitored time compressed magnetic tape is distinctive and would seem to permit rapid separation of gurglers from other types of sub ELF emissions.

The technique of aural monitoring was used in the present investigation to determine the times of occurrence of gurglers. However, sonagrams of these time periods exhibited some diversity in f-t characteristics. In general it appeared that a rising frequency fine structure was associated with a bubbling sound. However, the irregularly spaced fine structured elements often occur extremely close together and sometimes merge into an almost solid darkened area. In some cases it becomes difficult to ascertain whether or not rising frequency elements are present. When the separate elements cannot be observed, the emission appears as a "noise burst" (Pi 1). Hence a continuous f-t transition seems to occur between gurglers and noise bursts. From the standpoint of aural monitoring the characteristic bubbling sound varies in clarity for different events and seems to undergo a continuous transition to a roaring or crashing sound characteristic of noise bursts. On waveform records gurglers exhibit a fairly high degree of regularity and should be placed in a category about midway between Pc 1 (regular oscillations in frequency range 0.2-5 cps) and Pi 1 (irregular oscillations or noise bursts in the same frequency range).

The tendency for transitions to be continuous between all categories of sub ELF emissions is encountered in all of the 3 methods of classification discussed above: f-t displays, aural monitoring, and waveform records. In the present investigation times of occurrence of storm-time emissions were determined by aural monitoring. The statistical results given below are based on a combination of signals in and around the gurgler category and extending toward Pi 1 (noise bursts). For convenience in referring to signals in this transition region we use the term "gurgler - Pi 1".

III. SIMULTANIETY OF OCCURRENCE OF STORM-TIME EMISSIONS AT WIDELY SEPARATED STATIONS AND THE EXCITATION OF NATURAL EXOSPHERIC RESONANCES

As pointed out in the introduction, gurglers of the type shown in fig. 1 are not ordinarily observed at more than 1 or 2 of the Lockheed Pacific Ocean stations. However, signals in the transition gurgler - Pi 1 region have been observed simultaneously at all stations. Examples are given in the 4 station sonagrams of figs. 2 and 3. For these events the rising frequency structural elements blend together and are not sufficiently clear to permit a measure of their degree of simultaniety of occurrence at the 4 stations as was done for the structural elements of 8 hm emissions and for the gurgler of 10 Feb. 1963 (Tepley et al., 1963; Tepley, 1964; Tepley and Amundson, 1964a). However, by studying the 4 station sonagrams of figs. 2 and 3, several interesting effects are immediately apparent. Specifically, the band characteristics are different at each station. Furthermore the bands are often faintly visible long before the apparent start of the emission. It thus appears that the emission is initially characterized by a broad spectral energy distribution and that in certain frequency regions this energy strongly excites a natural resonance which had been previously weakly excited by energy from another source. The existence of these narrow bands of sub ELF energy has been reported previously (Tepley et al., 1964; Tepley and Amundsen, 1964b). The new observation reported here is the apparent increase in signal energy of the resonance bands produced by gurglers and gurgler - Pi 1 emissions. A model has been presented (Bostick and Prince, 1964) which explains many of the characteristics of the resonance bands (Tepley and Amundsen, 1964b).

Figure 1

Fine structured variety of storm type sub ELF emission

Note the irregularly spaced rapidly rising frequency structural elements. This type of signal when aurally monitored on time-compressed magnetic tape is characterized by a sound similar to bubbles being blown under water. This particular event was relatively intense at Palo Alto (about 100 milligammas) but was not observed at the other Lockheed Pacific Ocean stations. The vertical stripe in the center of the above sonagram is of instrumental origin. It represents F-M tape recorder noise and was produced during the interval when the magnetic tape was being changed.

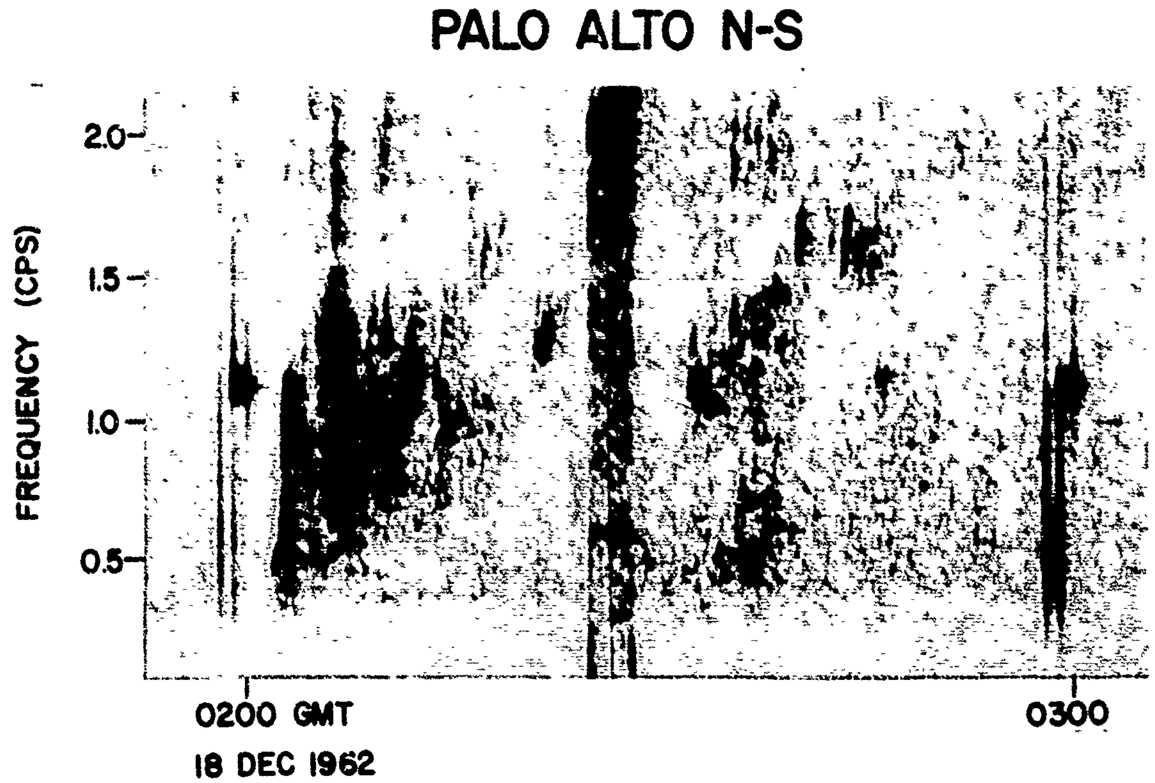

PALO ALTO N-S
FREQUENCY (CPS)
2.0
1.5
1.0
0.5
0200 GMT
0300
18 DEC 1962

Figure 2

Four station sonagrams of a storm-time sub ELF emission (5 July 1963)

The figure shows sonagrams of emissions in the intermediate gurgler - Pi 1 category. Traces of a closely spaced rapidly rising frequency fine structure can be found in the Palo Alto sonagram. However, the above emission more closely resembles a Pi 1 event (noise burst) than a gurgler. The signal differs from Pi 1 in that its energy is concentrated in a series of rather irregular bands which differ greatly between different stations. The energy in a noise burst is uniformly distributed over a broad spectral region.

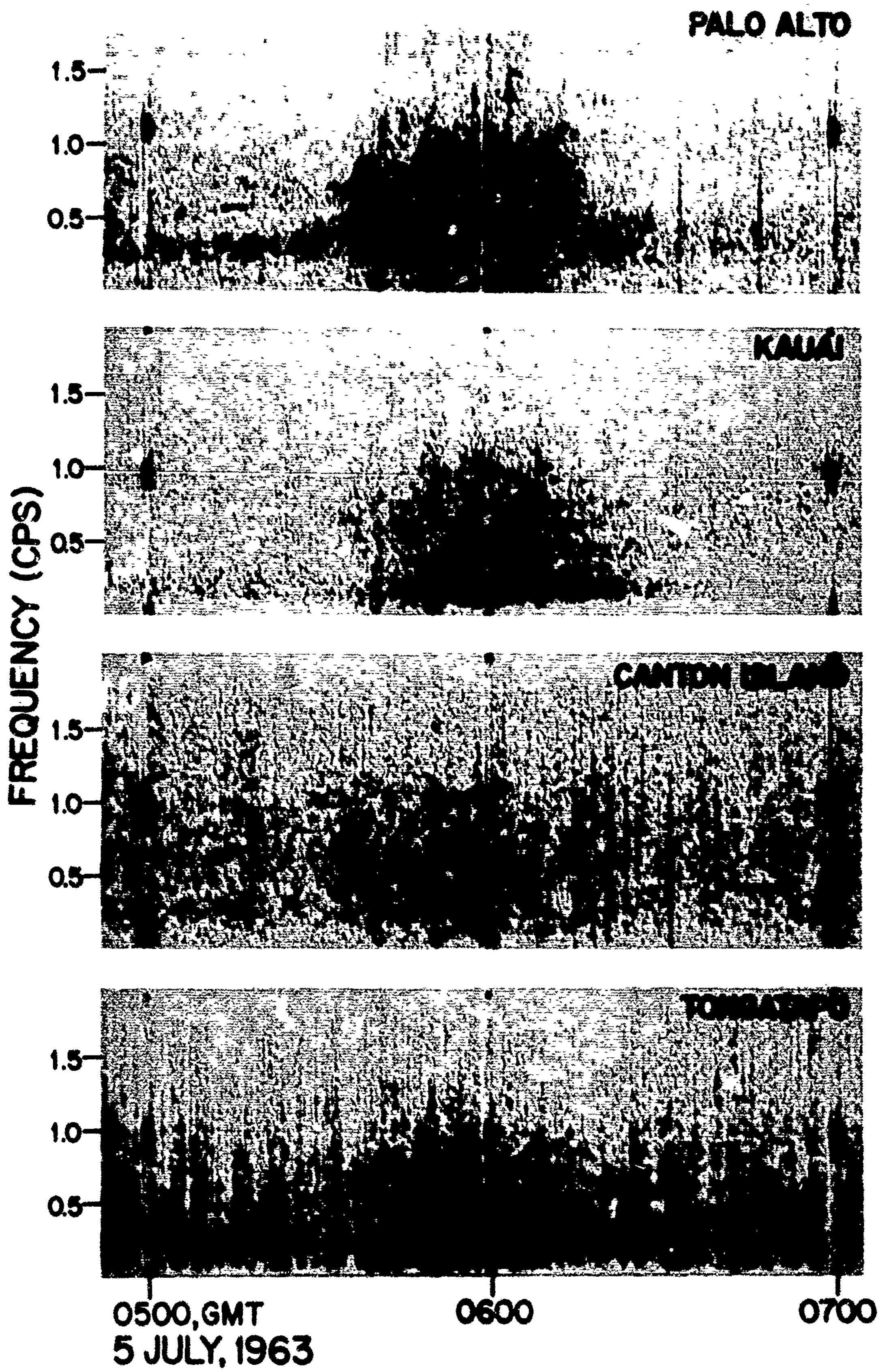
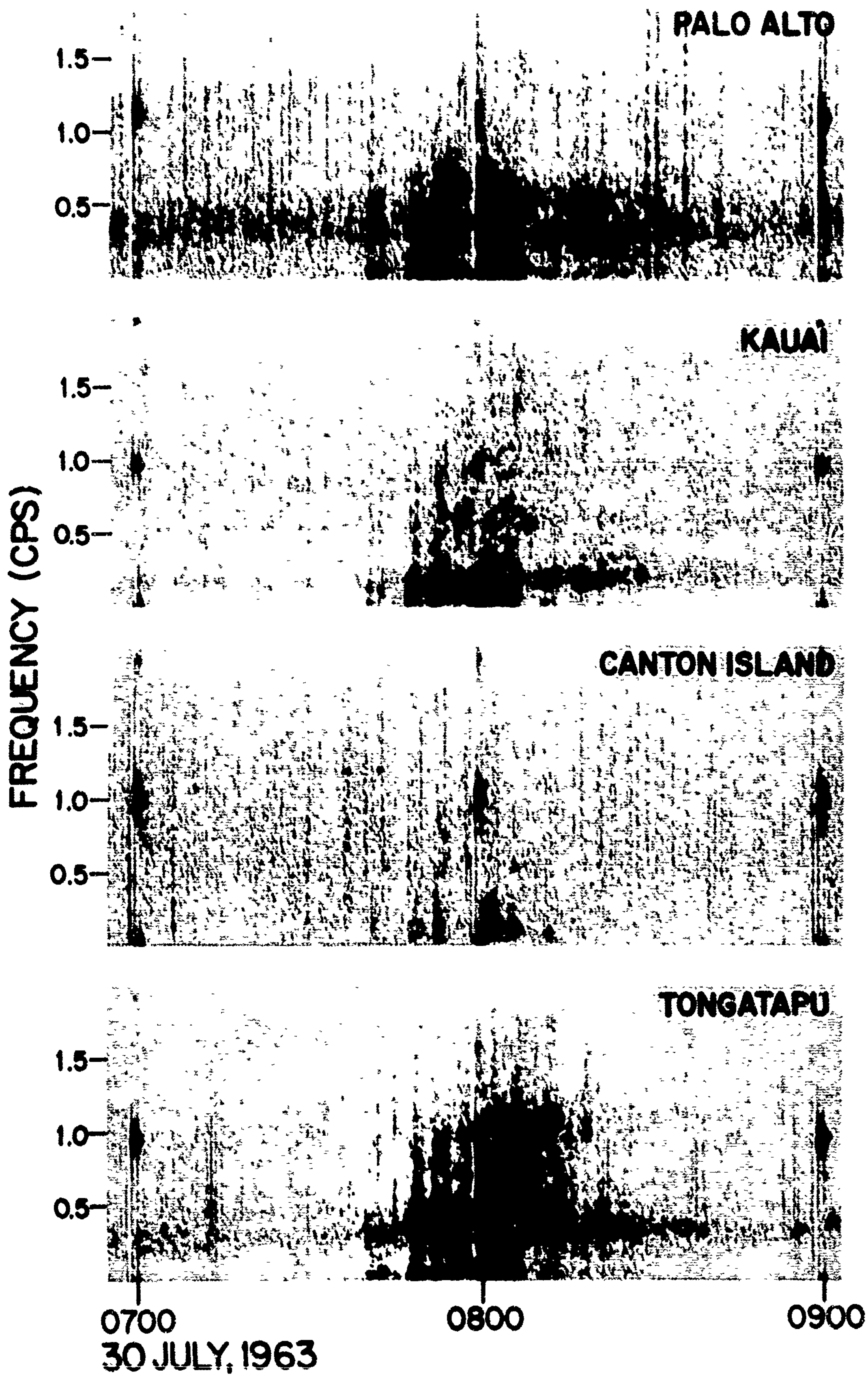

PALO ALTO
KAUAI
FREQUENCY (CPS)
1.5
1.0
0.5
0500,GMT
0600
0700
5 JULY, 1963

Figure 3

Four station sonagrams of a storm-time sub ELF emission (30 July 1963)

The event shown here is generally similar to that of the previous figure. Closely spaced rapidly rising frequency structural elements may be observed on both the Palo Alto and Tongatapu sonagrams. Note that both in this figure and in the previous figure, narrow bands of energy are observed before and after the intense portion of the emission. The bands are intensified during the intense portion of the signal. Thus it appears that the storm-time emissions excite naturally resonant oscillations or are intensified by the existence of natural resonant bands.


PALO ALTO
KAUAI
CANTON ISLAND
TONGATAPU
FREQUENCY (CPS)
1.5
1.0
0.5
0700
0800
0900
30 JULY, 1963

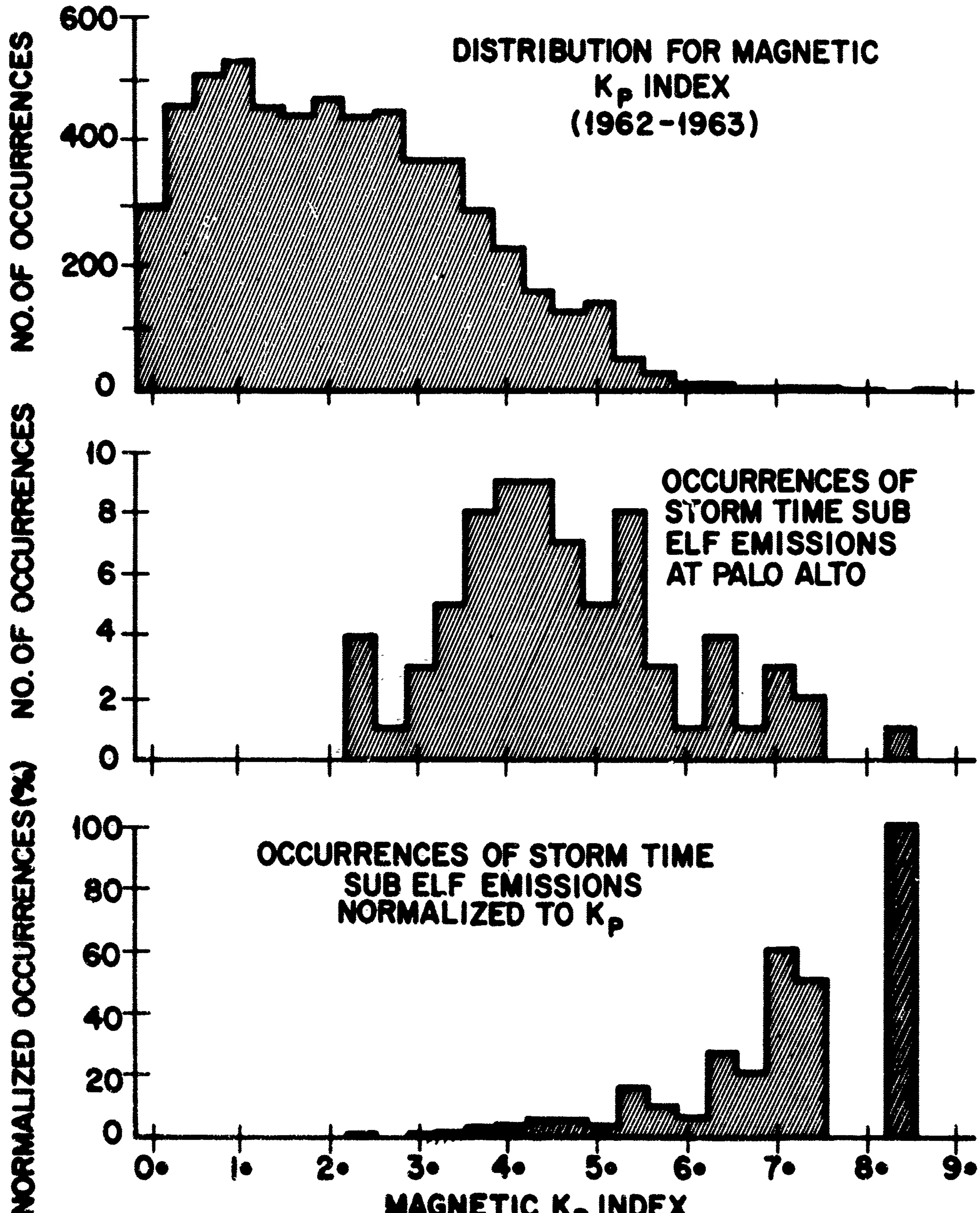

DISTRIBUTION FOR MAGNETIC
K$_p$ INDEX
(1962-1963)
NO. OF OCCURRENCES
600
400
200
0
OCCURRENCES OF
STORM TIME SUB
ELF EMISSIONS
AT PALO ALTO
NO. OF OCCURRENCES
10
8
6
4
2
0
OCCURRENCES OF STORM TIME
SUB ELF EMISSIONS
NORMALIZED TO K$_p$
NORMALIZED OCCURRENCES (%)
100
80
60
40
20
0
0• 1• 2• 3• 4• 5• 6• 7• 8• 9•
MAGNETIC K$_p$ INDEX

Fig. 4

IV. CORRELATION BETWEEN OCCURRENCE TIMES OF STORM-TIME SUB ELF EMISSIONS AND THE MAGNETIC Kp INDEX

In fig. 4 a plot is given of the number of occurrences of storm-time sub ELF emissions in the gurgler and gurgler - Pi 1 categories versus the magnetic Kp index. The times of occurrence of the emission were determined by aural monitoring of time compressed magnetic tape recorded at Palo Alto, California over the 2 year period 1962-1963. It is clear from the middle portion of the figure that the emissions tend to occur when Kp is relatively large. To present this effect in a more graphic manner it is desirable to consider the occurrences of the storm time emissions relative to the distribution in Kp. The latter quantity for the same 2 year period is plotted in the upper portion of the figure and shows that the relatively low values of Kp occur far more frequently than the high values. In the lower portion of the figure the occurrence of storm-time emissions are plotted normalized to the Kp distribution. It is clear that a strong correlation exists between the value of Kp and the probability of occurrence of gurglers and gurgler - Pi 1 emissions at Palo Alto.

V. TIMES OF OCCURRENCE OF STORM-TIME SUB ELF EMISSIONS

From observations of a limited number of gurglers, it was noted that the emissions tend to occur at Palo Alto in the late afternoon or evening before local midnight (Tepley and Amundsen, 1964a). To investigate this effect in more detail, the 2 year Palo Alto data sample for 1962-1963 was plotted against local time. The results, which include signals in the gurgler and gurgler - Pi 1 categories are presented in fig. 5. A

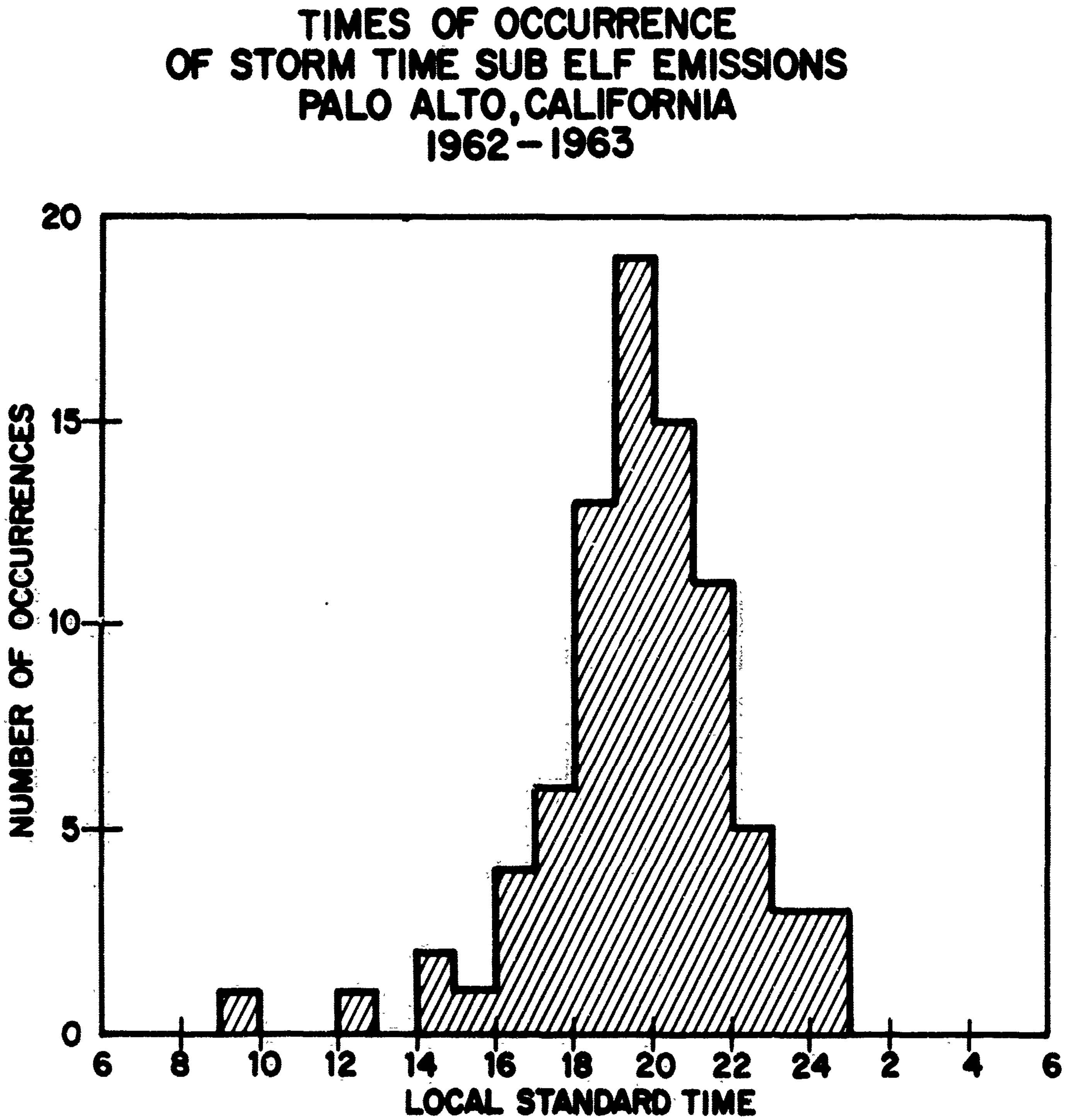

TIMES OF OCCURRENCE
OF STORM TIME SUB ELF EMISSIONS
PALO ALTO, CALIFORNIA
1962 - 1963
NUMBER OF OCCURRENCES
20
15
10
5
0
6
8
10
12
14
16
18
20
22
24
2
4
6
LOCAL STANDARD TIME

Fig. 5

pronounced maximum is noted near 800 PM local time.

It may be suggested that the evening maximum in occurrence of the emissions is due to decreased ionospheric attenuation of hydromagnetic waves after sunset. An effect of this type has been shown by Wentworth (1963, 1964a, b) to account for the strong increase in the number of occurrences of hydromagnetic emissions during the nighttime hours. To determine whether a similar effect might account for the nocturnal occurrence of emissions in the gurgler and gurgler - Pi 1 categories, the 2 year data sample was divided into 3 groups corresponding to 3 different time periods of local sunset. The results are plotted in fig. 6. It is seen that the distribution in occurrences of the emissions is not related in any simple way to the time of local sunset. Also the median occurrence time of the 3 distribution curves changes only slightly and is not related to the time of local sunset. The results of fig. 6 seem to indicate that the time distribution of occurrences of the emissions are not affected in a significant way by ionospheric hydromagnetic wave attenuation. Hence the occurrence maximum near 800 PM indicates a maximum in the source intensity at the same local time.

The 800 PM maximum seems to be statistically significant since it is based on 84 events observed at Palo Alto over a 2 year period. The median occurred at approximately 1945 local time. Two-thirds of the events fell between 1800 and 2230 so that the mean standard deviation in time is about 2 hours and 15 minutes. Therefore, the median for this distribution is about 2 mean standard deviations before local midnight.

The physical significance of signal occurrence during this time is

OCCURRENCES OF STORM-TIME SUB ELF EMISSIONS AT PALO ALTO RELATIVE TO SUNSET, 1962-1963

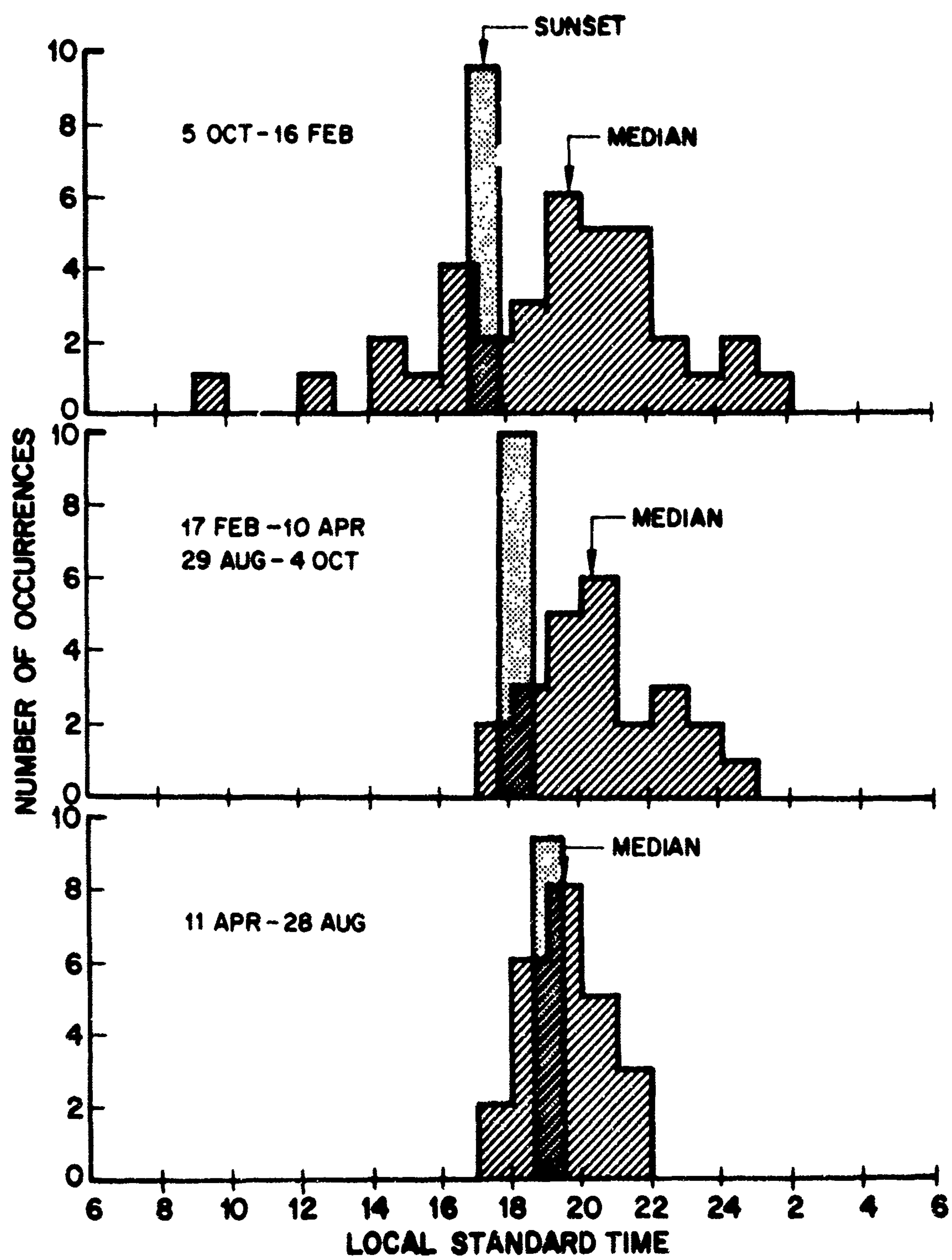


Fig. 6

unknown. However, other geophysical phenomena show local time behavior which is not symmetric with respect to the sun-earth line. For example, in the work of Wilson and Sugiura (1961) and Wilson (1962), it is concluded that hydromagnetic waves associated with magnetic storm SC's are characterized by clockwise polarization between 1000 and 2200 LT and by counter-clockwise polarization from 2200 to 1000. Wilson and Sugiura state that the polarization zones are fixed with respect to the sun, being divided roughly by a plane that points about 25° to the west of the sun. Other geomagnetic phenomena which tend to be asymmetric with respect to the earth-sun line are the Ds current system (Chapman, 1956) and the quiet-day polar current system Sq^p (Nagata and Kokubun, 1962).

Two model hypotheses have been advanced to explain such asymmetries: the first by Axford (1963) based on the effects of the co-rotation of the magnetosphere, and the second by Walters (1964) based on a bending of the solar wind at the shock front ahead of the magnetosphere.

The present observation of the occurrence times of gurgler - Pi 1 emissions may be interpreted as being associated with such an asymmetry. The significance of the observations must be treated with caution since the emissions cannot be placed in a well defined category but rather cover a transition region. Nevertheless the signals were selected by an objective system of aural monitoring so that the statistics seem to be valid.

Acknowledgements

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